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AUTHOR(S) B. E. Boyack, M. W. Cappiello, S. C. Harmony,
P. R. Shire, and D. A. Siebe

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 **Los Alamos** Los Alamos National Laboratory
Los Alamos, New Mexico 87545

ANALYSIS RESULTS FROM THE LOS ALAMOS 2D/3D PROGRAM*

by

B. E. Boyack, M. W. Cappiello,
S. C. Harmony, P. R. Shire, and D. A. Siebe

Safety Code Development
Nuclear Technology and Engineering Division
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

ABSTRACT

Los Alamos National Laboratory is a participant in the 2D/3D program. Activities conducted at Los Alamos National Laboratory in support of 2D/3D program goals include analysis support of facility design, construction, and operation; provision of boundary and initial conditions for test-facility operations based on analysis of pressurized water reactors; performance of pretest and posttest predictions and analyses; and use of experimental results to validate and assess the single- and multi-dimensional, nonequilibrium features in the Transient Reactor Analysis Code (TRAC). During fiscal year 1987, Los Alamos conducted analytical assessment activities using data from the Slab Core Test Facility, the Cylindrical Core Test Facility, and the Upper Plenum Test Facility. Finally, Los Alamos continued work to provide TRAC improvements. In this paper, Los Alamos activities during fiscal year 1987 will be summarized; several significant accomplishments will be described in more detail to illustrate the work activities at Los Alamos.

INTRODUCTION

The 2D/3D program is sponsored jointly by Japan, the Federal Republic of Germany, and the United States (US). The safety-related objectives of the 2D/3D program are as follows: first, to provide an improved understanding of the effectiveness of various emergency core-cooling (ECC) systems in limiting peak fuel rod cladding temperatures during vessel refill and core reflood for medium- to large-break loss-of-coolant accidents (LOCAs) in pressurized water reactors (PWRs); second, to reveal core-coolant inventory and system flow characteristics during the refill and reflood phases of a medium to large-break LOCA; third, to study convective flow and temperature distributions inside a heated core during reflood for a medium- to large-break LOCA; fourth, to assess the predictive capability of best-estimate computer codes and the conservatism of evaluation-model computer codes; and fifth, to obtain information which

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may be used to improve thermal-hydraulic models in best-estimate, evaluation-model and other computer codes.

Activities conducted at Los Alamos National Laboratory in support of 2D/3D program goals include analysis support of facility design, construction, and operation; provision of boundary and initial conditions for test facility operations based on analysis of PWRs; performance of pretest and posttest predictions and analyses; and use of experimental results to validate and assess the single- and multidimensional, nonequilibrium features in the Transient Reactor Analysis Code (TRAC).

Three experimental facilities provide data to 2D/3D program participants. The Slab Core Test Facility (SCTF) is a separate-effects reflood facility located in Japan. It models a full-height 1/21-scale section of the core, one fuel element wide from core centerline to outer periphery. This facility began testing with its third electrically heated core during 1986; Los Alamos will continue analysis of Core-III tests in FY-1988. The Cylindrical Core Test Facility (CCTF) is an approximately 1/21-scale facility, also located in Japan; this facility has completed its test program and the Los Alamos counterpart analysis program is nearing completion. The Upper Plenum Test Facility (UPTF), located in the Federal Republic of Germany, is a 1/1-scale integral test facility focusing on phenomena in the downcomer, lower plenum, upper plenum, and primary-system loops of a PWR. Los Alamos analytical efforts to date have largely supported test design and specification; posttest analyses of UPTF experiments have started and will be emphasized during FY-1988; in part because of the importance of these efforts in supporting an effort to quantify the uncertainty associated with TRAC predictions of peak cladding temperatures for large-break LOCAs.

During FY-1987, Los Alamos conducted analytical assessment activities using data from the SCTF, CCTF, and UPTF facilities. Finally, Los Alamos continued efforts to provide improvements to the TRAC code. This paper summarizes Los Alamos activities during FY-1987; several significant accomplishments are described in more detail to illustrate the work activities at Los Alamos.

TRAC ASSESSMENT ACTIVITIES

A few comments are appropriate to introduce the summary comments that will be provided to describe our TRAC-PF1/MOD1 (Ref. 1) assessment activities. When performing a code assessment, understanding must be developed, catalogued, and reported in three vital areas. These three areas are (1) sufficiency of knowledge about the as-built and as-operated state of the facility providing the data to be used for assessment, (2) the adequacy of the input model prepared to describe the facility, and (3) the adequacy of the closure models and correlations within the code.

Now consider a situation in which some significant feature of the plant configuration or operation is either unknown or undetected by the individual performing a posttest assessment. This deficiency of knowledge will be reflected in the input model and in the calculated result. Lacking knowledge that the deficiency exists, the analyst will tend to assign fault incorrectly to either the adequacy of the input model or the adequacy of the closure models and correlations within the code. Consider, for example, a second example in which the overall knowledge of the facility and its operation is good; i.e., the perception of the plant configuration and operation is accurate, but the calculated and measured results do not agree in significant respects. The cause for the disagreement(s) can lie with either the adequacy of the input model or the

adequacy of the code closure models and correlations or with some combination of the two. Care must be taken to determine the cause. Problems associated with the input model can frequently be remedied and user guidelines issued to alert others to the problem. Problems associated with the code closure models and correlations frequently require more effort to correct. A decision must be reached as to whether code model and correlation improvement should be attempted or whether the deficiency should be accepted as part of the quantified code uncertainty for related transients.

As we summarize our CCTF, SCTF, and UPTF posttest assessment activities, we will attempt to use the framework identified above. It is hoped that this will provide a cohesive structure for identifying the "lessons learned" during these assessment activities.

SCTF PROGRAM SUPPORT

We will summarize results for three SCTF posttest assessment activities at Los Alamos, Runs 704, 713, and 714. The versions of TRAC-PF1/MOD1 used for these analyses were version 13.1 for Run 704, 13.0 for Run 713, and 13.1 for Run 714. A detailed analysis discussion is provided for Run 704, with more concise discussions for Runs 713 and 714. For all figures in this paper comparing calculated and test results, the calculated results are shown as a solid line and the data as a dashed line. In addition, the figures frequently carry a legend identifying the JAERI identification number for that data item. In the legend, the corresponding TRAC calculated value carries the prefix "C."

SCTF Run 704 (Ref. 2) is a German PWR (GPWR) evaluation-model integral orientation test. Run 704 was one of the first GPWR tests. Important features of the test specification included a blowdown of the initial primary pressure from 0.6 MPa to 0.3 MPa and multiple ECC-system injections into the cold leg, four locations in the upper plenum and two locations above the upper core support plate. Many interesting phenomena occurred during the test. The posttest calculation and analysis effort for Run 704 are also interesting because information was obtained in each of the three assessment areas identified above. Figure 1 displays the measured and calculated differential pressure in bundle 5 over the full core height. The differential pressure can also be considered as a direct measure of the liquid level in the bundle. During the test, the liquid level in the bundle generally increased until about 200 s, when the liquid level in the core was severely depressed. The liquid level subsequently began to recover at about 245 s. The TRAC-calculated liquid level trace showed a similar trend but was noticeably different in magnitude. In particular, the increase in liquid level stalled at about 170 s and the calculated depression in liquid level occurred later (at about 220 s) and was deeper than measured. In fact, liquid displaced from the core passed into the lower plenum, up the downcomer, and out the broken cold leg on the pressure vessel side. This liquid was lost from the system and not available for subsequent core cooling. One consequence of the greater liquid-level depression and loss of core coolant calculated by TRAC was a dryout and heating of the high-elevation cladding not seen in the test, as shown in Fig. 2. A number of lessons were learned during the course of the posttest analysis. These are summarized below using the categories previously discussed.

Overall, our knowledge of the facility configuration and operation is very good. However, the GPWR integral orientation test Run 704 was among the first in a new test series having conditions markedly different than tests previously analyzed. In particular, the quantity of ECC liquid injected into the upper plenum was large; much of this liquid was carried out

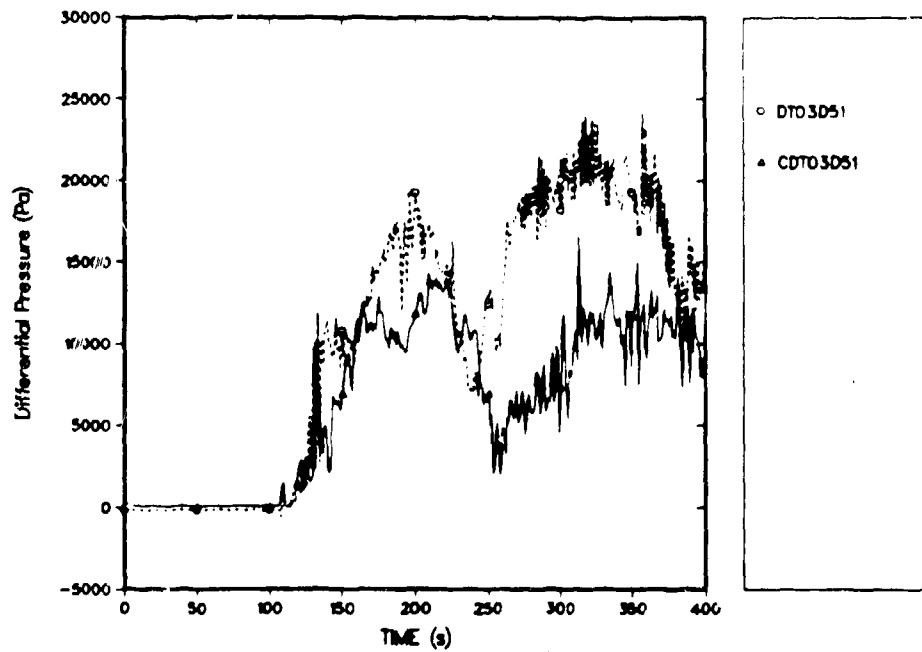


Fig. 1.
Bundle 5 liquid levels for SCTF Run 704.

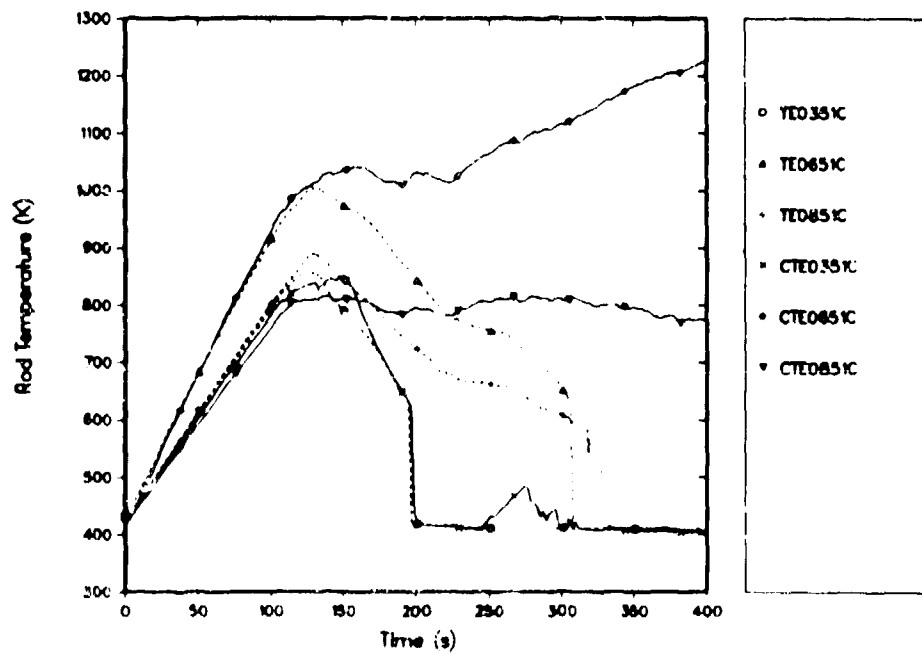


Fig. 2.
Bundle 5 cladding temperatures for SCTF Run 704.

of the upper plenum, through the hot leg, and into the steam/water (S/W) separator. The facility is equipped with a trip-activated drain line that is activated when the liquid level in the S/W separator reaches 1 m. During the test, the trip level was activated at 190 s and the drain line removed between 5.5 and 7.5 kg/s thereafter. Nevertheless, the S/W separator continued to fill, and by 200 s liquid in the S/W separator was being entrained and carried from the S/W separator to containment tank II. The increased pressure drop associated with two-phase flow increased the S/W separator, hot-leg, and upper-plenum pressures and caused the core liquid level depression seen in Fig. 1. The same phenomena were calculated in TRAC; however, there were some important differences. To our knowledge, Run 704 was the first test analyzed by Los Alamos in which the drain line was activated; thus, we had not considered it in our previous SCTF analyses. Therefore, the TRAC calculation did not model the liquid removed from the S/W separator by the drain line. This example illustrates a case in which the analyst's knowledge of the facility configuration and operation was inadequate.

We gained important information about our SCTF Core-III input model during our posttest calculation and analysis of SCTF Run 704. This input model had been recently created for the SCTF Core-III configuration. Relative to the earlier Core-II input model, it featured finer axial noding in the region of the upper plenum because modification of the upper plenum internals to model the GPWR was the primary difference between the SCTF Core-II and Core-III configurations. This finer axial noding extended into the downcomer region because axial noding is preserved at all radial nodes in the VESSEL component. The calculation of SCTF Run 704 was the second application of a newly developed input model created for the recently installed SCTF Core III. The first application of the new Core-III input model was for SCTF Run 714, which was a relatively simple test in that the only ECC injection was directly into the lower plenum and there was no primary-system blowdown.

No input model problems were identified during the analysis of SCTF Run 714. However, use of the finely noded SCTF Core-III input model produced a calculated result in which there was insufficient agreement between the calculated result and the data. In the calculation, essentially all ECC liquid injected into the cold leg bypassed the core through the broken cold leg on the pressure-vessel side. The lower plenum did not refill during the calculated transient as in the test. It was determined that the small axial downcomer noding below the level of the loop cold-leg nozzles caused the TRAC cell-based constitutive package to predict that the liquid flowing into the downcomer from the intact cold leg was in the slug flow regime, a regime of high drag. Rather than penetrating the downcomer to the lower plenum, the liquid remained suspended in the downcomer until it was entrained by steam flowing up one side of the downcomer and out the broken cold leg. Because the cell-based calculation structure is inherent to the TRAC code, the immediate remedy was to revise the VESSEL noding. A reduced number of nodes was used in the downcomer below the intact cold leg. With the reduced noding, a more nearly correct flow regime was predicted by TRAC and the downcomer penetration observed in the test was calculated. A more extensive discussion of this problem is found in the posttest analysis report.³

Additional information about the input model was obtained from the calculation using the reduced noding just described. In our discussion of the predicted core liquid level (Fig. 1), we noted that the predicted core liquid-level increase stalled at about 160 s. We determined that this was the time at which the calculated S/W separator liquid level exceeded the height

of the lowest cell, or level one in the S/W separator model. The next cell, or level two above, included the junction of the broken cold leg on the S/W separator side to containment tank II. We should note that the TRAC model prepared for the S/W separator does not maintain a sharp liquid-level interface. Thus, as liquid enters a cell, a two-phase mixture is predicted and donor-celled into the broken cold leg. The pressure drop through the line increases, elevating the S/W separator, hot-leg, and upper-plenum pressures. The two phase flow was sufficient to stall the refilling of the core as seen in Fig. 1 beginning at about 160 s. The calculated sharp liquid-level depression beginning at about 225 s corresponds to the time when the cells at level two are about half full, *i.e.*, full to the nozzle, and the pressure drop through the line from the S/W separator to containment tank II further increases.

Two modifications that should be made to the reduced-noding SCTF Run 704 model are evident. First, the S/W separator noding should be modified. Although there are several approaches for doing so, it would seem that several additional levels should be included below the nozzle level in the S/W separator. In addition, a S/W separator drainline model should be added as the S/W separator liquid level is reduced by approximately 1 m during every 150-s period in the test. This corresponds to a drain rate of 5.5 to 7.5 Kg/s.

We now consider the question usually asked in a posttest assessment activity. How well did the code do in predicting the transient and what was learned about deficiencies in the code constitutive models and correlations? We must first note that inadequacies in our knowledge of the facility configuration and operation resulted in failure to model a significant component in the transient, the S/W separator line. In addition, the S/W separator noding was too coarse. These understandings are important in and of themselves to the assessment analyst and prospective code users. However, these defects strongly affected the course of the calculation beginning early in the transient [about 60 s after bottom-of-core recovery (BOCREC)] and limited our ability to assess how well the code was able to simulate SCTF Run 704. We did determine that over the limited time in which useful results for code assessment were generated, the interfacial shear in the upper plenum was too high. Details of this code deficiency have been documented in Ref. 4.

SCTF Run 713 (Ref. 5) is a United States/Japan (US/J) evaluation-model test. Important features of the test specification included a steep power profile (bundles 1-2 at a relative power of 1.0, bundles 3-4 at 1.2, bundles 5-6 at 1.0, and bundles 7-8 at 0.8), and ECC injection into the lower plenum only. The peak rate of accumulator injection was 37 kg/s beginning at 74 s after transient initiation; low-pressure coolant injection (LPCI) of 3.75 kg/s began at 180 s. Several interesting phenomena were observed and calculated in this test. Figure 3 is a display of the integrated core-exit liquid flow calculated by TRAC for each of the eight heater-rod bundles in the SCTF facility. Flow is greatest in the high-powered bundles 3 and 4 and smallest in the low-powered bundles 7 and 8; there was reverse flow in bundle 8 after 450 s. This overall behavior is consistent with two-dimensional core flow and is caused by the sharply varying radial power profile. The enhanced heat transfer in high-powered bundles has been studied by JAERI for SCTF Core II and results in a greater steam-generation rate and increased liquid entrainment.⁶ As shown in Fig. 3, TRAC also predicts increased liquid flow above the high-powered bundles 3 and 4.

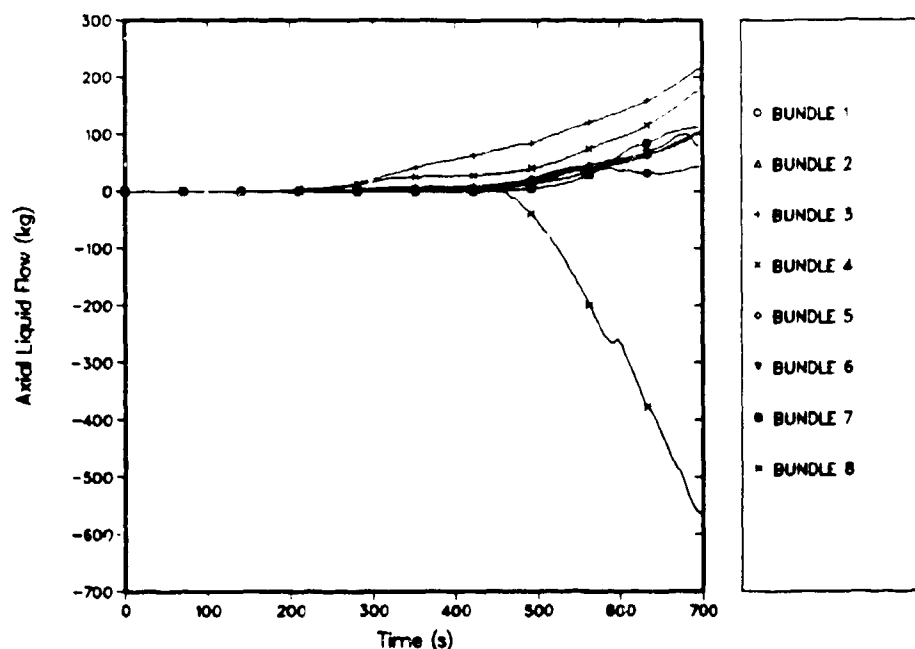


Fig. 3.
Integrated core-outlet liquid flow for SCTF Run 713.

Calculated and measured cladding temperatures in high-powered bundle 4 are presented in Fig. 4. Both the calculated peak cladding temperatures and time of quench are judged to be in reasonable agreement with the data. One trend calculated to occur and not evident in the data is a reheat at the three-quarter plane (about 200 s) and midplane (about 325 s) positions. This reheat is due to a sudden decrease in the heat-transfer coefficient resulting from the TRAC interface-sharpener model. The action of the interface-sharpener is illustrated in Fig. 5 at a position just above the core midplane (core elevation 1.905 m). Calculated void fractions remain at or near pure vapor longer than observed in the test and then suddenly decrease to a value much lower than that observed in the test. Efforts are in progress to remedy this deficiency in the TRAC-PF1/MOD2 code. Preliminary results describing this effort are presented later in the paper. Calculated and measured cladding temperatures in bundle 2 are presented in Fig. 6 as typical of the cladding temperature behavior calculated in all the moderately powered bundles 1, 2, 5, and 6. Compared with the data, too little cooling is calculated above the quench front as shown by the calculated cladding temperature behavior at the midplane and three-quarter-plane levels. From the information available, we infer that the calculated chimney effect above the high-powered bundles 3 and 4 is too strong. That is, the moderately powered bundles adjacent to the high-powered bundles are starved as liquid is entrained by the more rapidly upflowing vapor stream above the high-powered bundles 3 and 4 (see Fig. 3 for the calculated liquid exiting the core above each bundle). Passage of the quench front calculated by the interface sharpener can be observed at the midplane in Fig. 6.

We summarize our conclusions related to the posttest analysis of SCTF Run 713 using the categories previously discussed. We feel that our overall knowledge of the SCTF facility

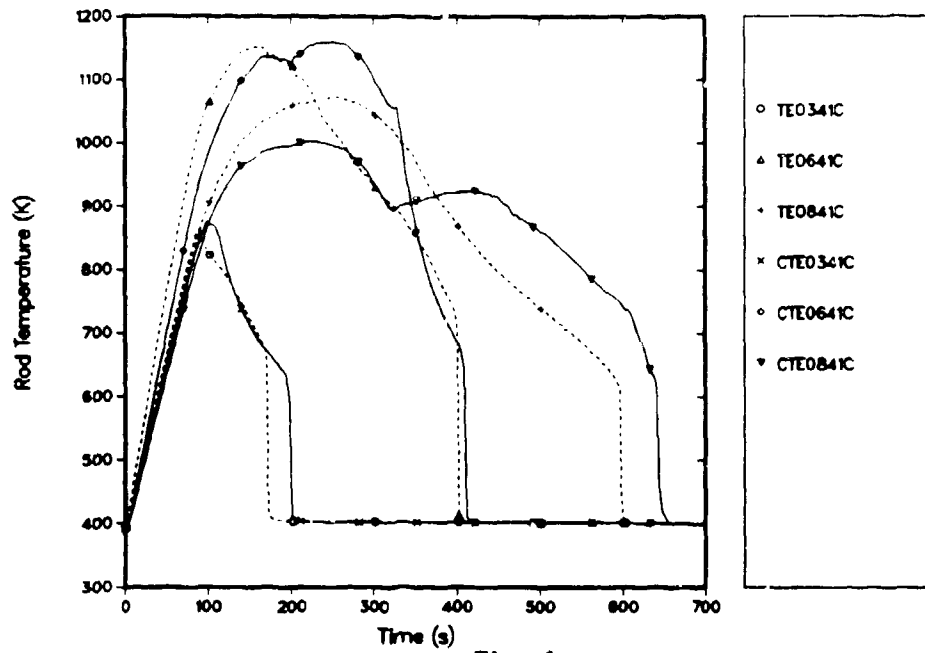


Fig. 4.
Bundle 4 cladding temperatures for SCTF Run 713.

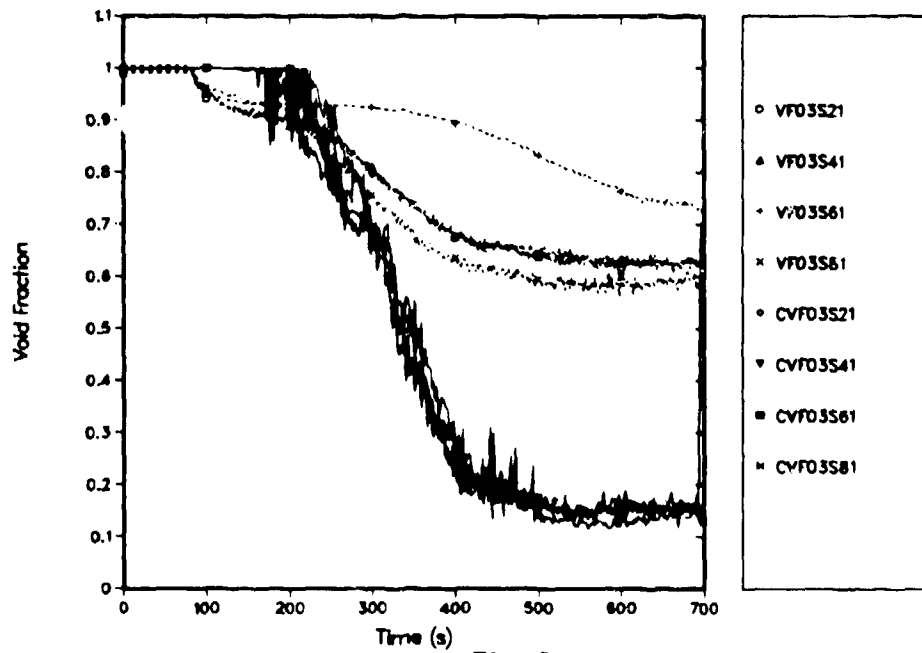


Fig. 5.
Bundles 2, 4, 6, and 8 void fractions at the 1905-mm level for SCTF Run 713.

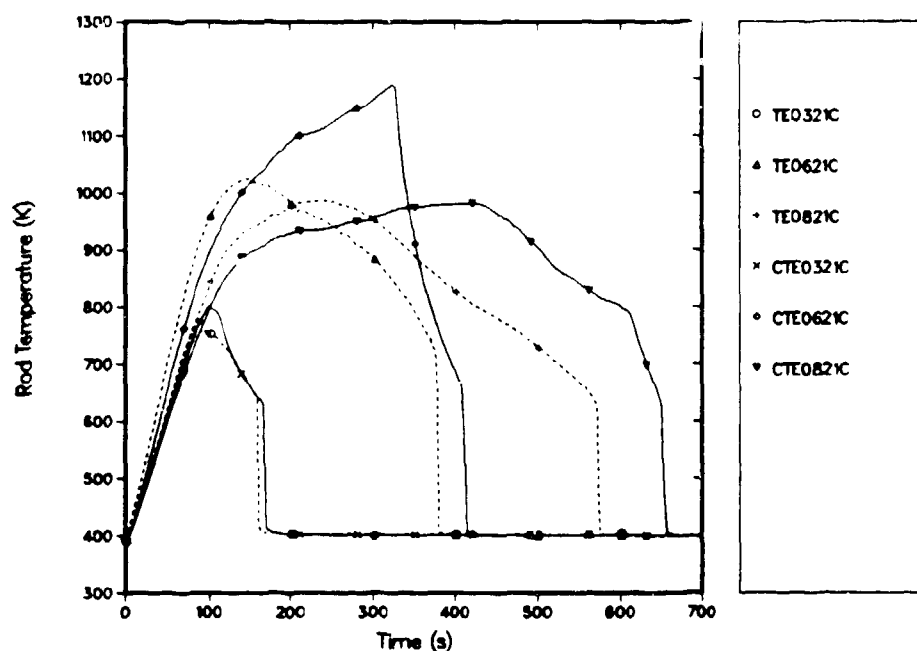


Fig. 6.
Bundle 2 cladding temperatures for SCTF Run 713.

configuration and operation is good. We could identify no deficiencies in our knowledge about either facility configuration or operation for SCTF Run 713. No input model deficiencies were identified during the analysis of SCTF Run 713. However, we remind the reader that this same finely noded model was found to be inadequate when used for the calculation of SCTF Run 704. With regard to the adequacy of the code constitutive models and correlations we draw the following conclusions: (1) TRAC generally calculates the major trends of the test, (2) the calculated two-dimensional flow pattern predicted is consistent with that inferred to exist in the test facility, (3) it appears that the calculated chimney effect above the high-powered bundles is too intense and that adjoining moderately powered bundles are starved of coolant, and (4) the interface sharpener further reduced cooling in the starved bundles. Posttest assessment results for SCTF Run 713 are summarized in Ref. 7.

SCTF Run 714 (Ref. 8) is a US/J best-estimate test. Important features of the test specification included a two-step power profile (bundles 1–4 at a relative power of 1.1 and bundles 5–8 at 0.9) and ECC injection into the lower plenum only. The peak rate of accumulator injection was 100 kg/s beginning at 67 s after transient initiation and LPCI at 5.3 kg/s beginning at 84 s. Relative to evaluation-model test Run 713, the ECC injections occurred earlier and were at a higher rate. Overall, the agreement between the calculated and measured results was reasonable with the exception of the time of core quench, which was predicted to occur too early. This means that the calculated phenomena generally were as in the test. However, assessment analyses tend to emphasize those phenomena which were not precisely calculated, even if the effect is second order on key parameters such as cladding temperature. Figure 7 displays the calculated and measured upper-plenum measured pressures. The system

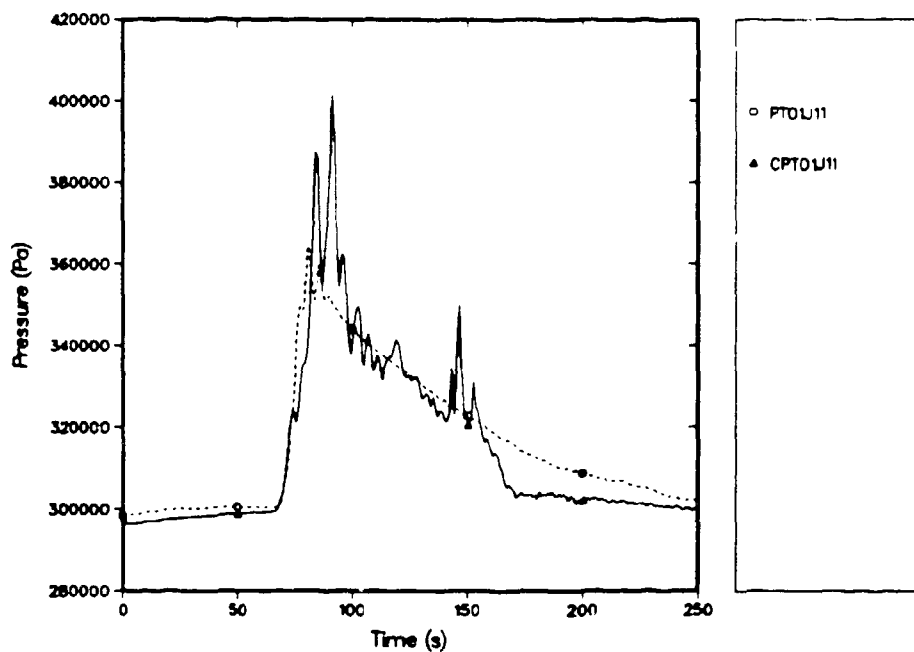


Fig. 7.

Upper plenum average pressures for SCTF Run 714.

pressure increases sharply as liquid enters the core beginning at about 70 s at the time of BOCREC. However, the calculated pressure is too high, indicating too much steam generation in the core. The core reflooding is illustrated in Fig. 8, which compares the differential pressures (liquid levels) in bundle 3. Following BOCREC, large oscillations in liquid level are both observed and calculated. However, the measured oscillations damp out more rapidly than those calculated. The calculated oscillations appear to be of greater magnitude, as shown by a higher calculated downcomer liquid level in Fig. 9. One consequence of the higher liquid level is the calculated loss of system inventory through the broken cold leg on the pressure-vessel side, as shown in Fig. 10; this did not occur in the test. A second consequence is that large amounts of liquid are carried into the upper plenum as shown in Fig. 11. As this liquid passes through the core, it cools the upper portions of the cladding at a faster rate than measured in the test, as shown in Fig. 12. This excess calculated heat transfer results in a calculated quench of the core about 80 s earlier than measured. A careful examination of the calculated results indicates that the excessive core heat transfer and steam generation calculated may be related to the limited number of thermal-hydraulic nodes in the core; *i.e.*, the problem may be noding related. The bursts of steam generation and related liquid pulses into the upper plenum and downcomer result from near simultaneous quenching in several sections of the core. This is most evident for the final core quench at about 155 s but can also be related to earlier core quenches shortly following BOCREC. Clearly, there is a physical basis for this phenomenon as the measured core behavior is similar. However, increased noding may lead to an earlier end to the oscillations in the calculation and a result that more nearly simulates the test.

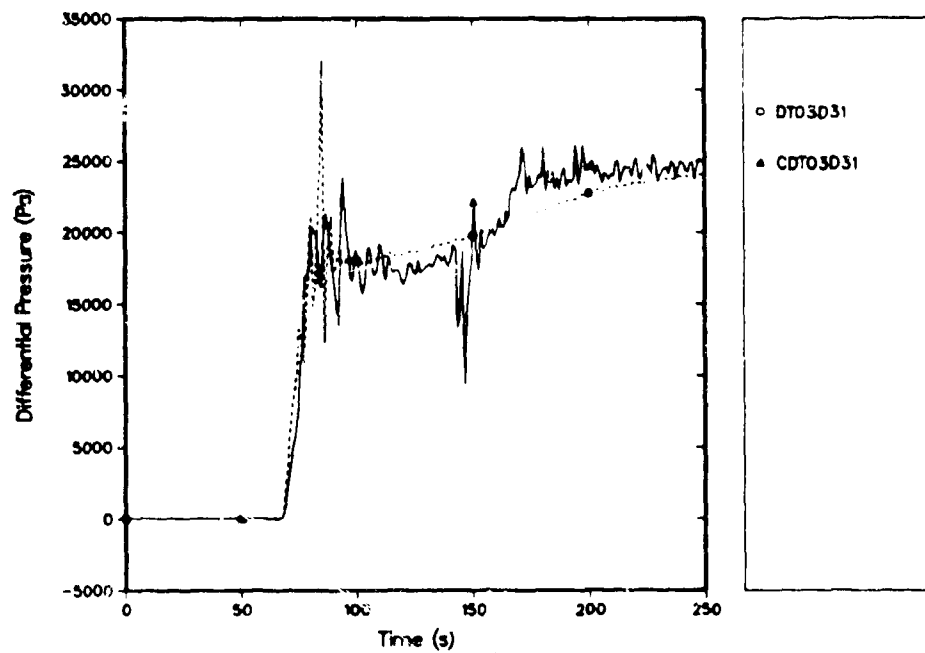


Fig. 8.
Bundle 3 liquid levels for SCTF Run 714.

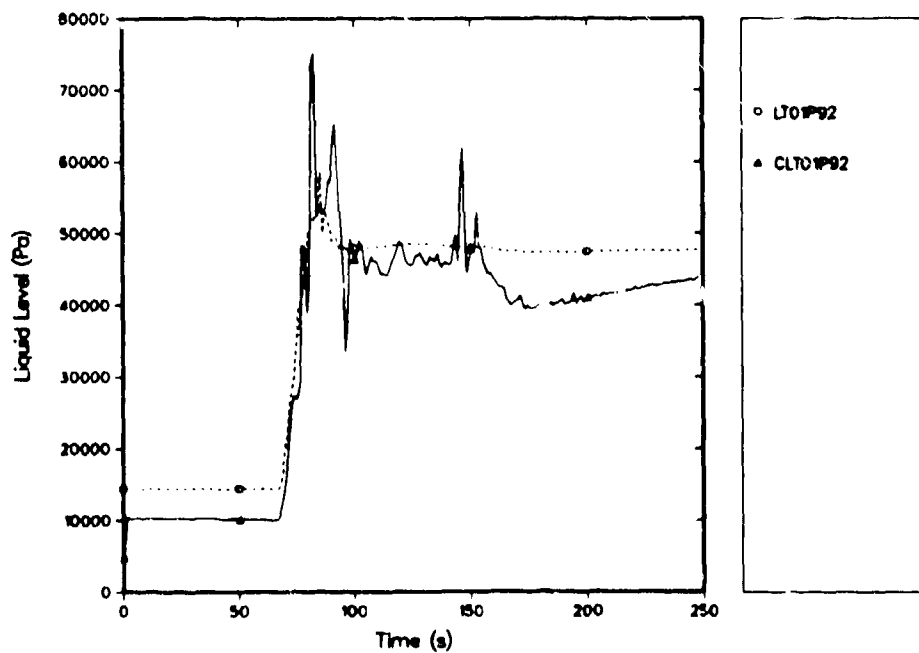


Fig. 9.
Downcomer liquid levels for SCTF Run 714.

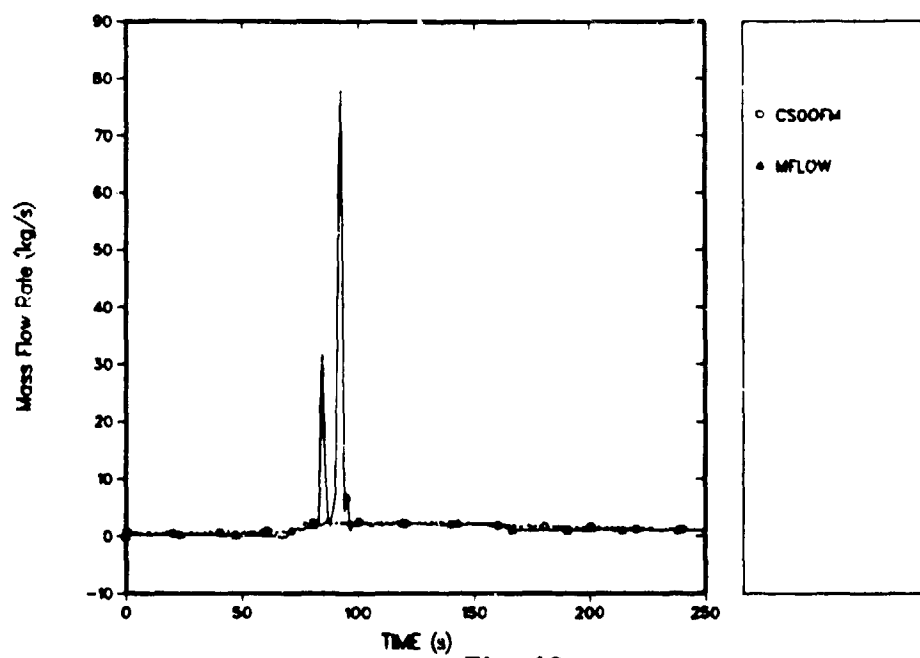


Fig. 10.

Mass flows in the broken cold leg pressure-vessel side for SCTF Run 714.

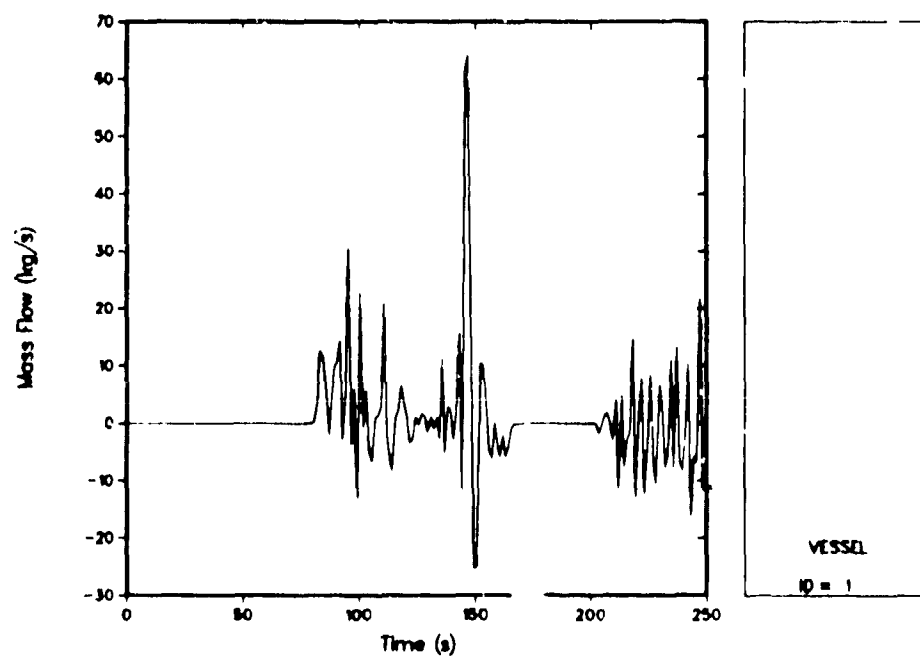


Fig. 11.

Core-outlet liquid mass flows for SCTF Run 714.

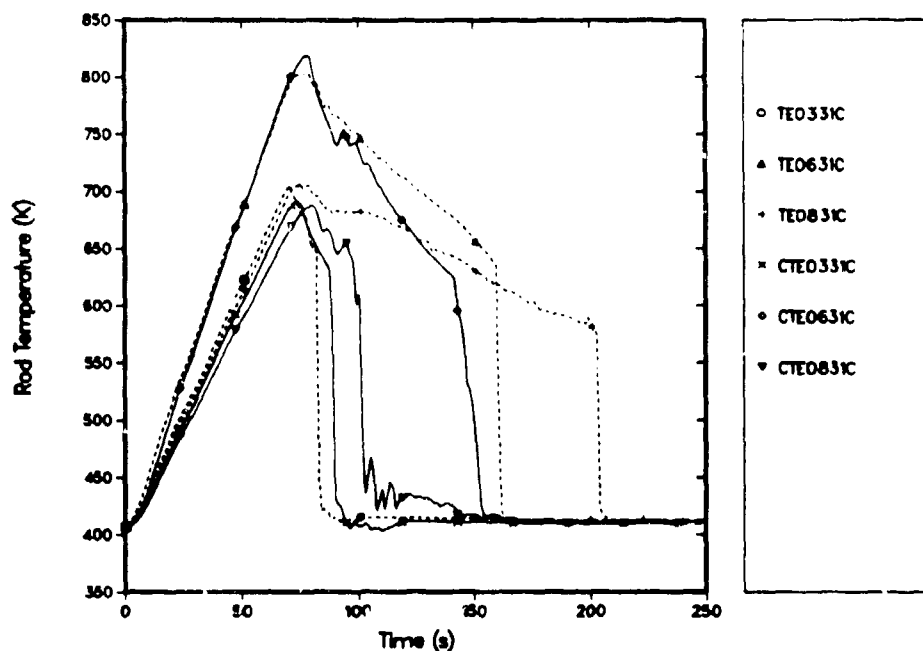


Fig. 12.
Bundle 3 cladding temperatures for SCTF Run 714.

We summarize our conclusions related to the posttest analysis of SCTF Run 714 using the categories previously discussed. We feel that our overall knowledge of the SCTF facility configuration and operation is good. We could identify no deficiencies in our knowledge about either facility configuration or operation for SCTF Run 714. No major input model deficiencies were identified during the analysis of SCTF Run 714. However, the excessive heat transfer occurring following BOCREC does have the appearance of being noding sensitive. We believe that an additional noding study could prove whether the calculation has a sensitivity to the number of core thermal-hydraulic nodes and quantify the effect if it existed. Finally, we remind the reader that this same finely noded model was found to be inadequate when used for the calculation of SCTF Run 704. With regard to the adequacy of the code constitutive models and correlations we draw the following conclusions: (1) TRAC generally calculates the major trends of the test, (2) the excessive steam generation in the core may be related to the code constitutive models and correlations (however, the noding study discussed above would be a prerequisite to evaluating whether or not a code deficiency exists), and (3) too little liquid is carried into the upper plenum following BOCREC. This is related to the interface-sharpener model in the core which generally retains too much liquid below the interface and allows too little above the interface. Posttest assessment results for SCTF Run 714 are summarized in Ref. 9.

CCTF PROGRAM SUPPORT

CCTF Run 58 (Ref. 10) is a combined downcomer and cold-leg injection test. Test initiation began with the primary steam filled except for the downcomer, which contained 0.86 m water. Downcomer injection began at 85.5 s and continued to 100.8 s at about 8.5 kg/s. ECC injection into the lower plenum simulated accumulator injection at the rate of approximately 92 kg/s and lasted from 85.5 s to 97.0 s when ECC injection was switched to the cold leg. The ECC injection into the cold leg first continued the simulation of accumulator injection at 79 kg/s until 111 s then switched to the LPCI rate of approximately 2.1 kg/s which continued until 1008 s. The test was characterized by a long-term manometric-type oscillation that occurred between the downcomer and the core.

After a close examination of the test results, JAERI concluded that when subcooled water in the downcomer rose to the level of the cold-leg nozzles, some of the water was entrained by steam flowing from the intact cold legs, through the downcomer, and into the broken cold leg. This cold water condensed steam in the downcomer and broken cold leg, causing a decrease in the pressure at the top of the downcomer. The pressure difference between the upper plenum and the vessel, which provides the driving potential for flow through the intact loops, increased and caused a surge of fluid, mostly steam, to flow into the downcomer. This in turn caused the pressure in the downcomer to rise and the liquid level in the core to fall, with liquid forced into the core. As some of this liquid vaporized, the pressure in the core increased and reversed the inflow. This forced the water to rise again in the downcomer, leading to the start of the next cycle. The oscillation occurred at the manometric frequency and seemed to be a resonant condition. Every second oscillation, sufficient water from the ECC injection had accumulated in the downcomer to allow the level to reach the cold-leg nozzle elevation.

A comparison of calculated and measured downcomer liquid level (Ref. 11) is presented in Fig. 13. It can be seen that a slightly higher average downcomer liquid level was calculated but that the magnitude of the calculated oscillation was much less than measured. It appears that TRAC underpredicts the entrainment of downcomer liquid by vapor passing from the intact loops into the broken cold leg. As a consequence, too little condensation is predicted to occur in the broken cold leg. A related outcome of too little condensation is that the pressure differences driving the oscillations are underpredicted. Thus, TRAC shows a smaller oscillation than in the test. Because liquid is repeatedly carried into the broken cold leg during the level oscillations and this phenomenon is not calculated, more liquid is calculated to remain in the vessel. The presence of additional liquid above that measured in the test can be seen in Fig. 14, which compares the calculated and measured liquid levels in the upper half of the core. After about 200 s, excess liquid is calculated. As previously discussed, TRAC consistently predicts too little liquid above the quench front because of its interface-sharpener model. Thus, the excess calculated liquid indicates a higher calculated liquid level than measured.

We summarize our conclusions related to the posttest analysis of CCTF Run 58 using the categories previously discussed. We feel that our overall knowledge of the CCTF facility configuration and operation is good because many tests have been conducted and analyzed. However, some deficiencies in our knowledge about the configuration and operation of the facility for Run 58 were identified. First, the open/shut status of the reactor vent valves (RVVs) was unclear when the first posttest calculation and analysis were performed. The actual status of the RVVs was shut; Los Alamos assumed the valves were open. Second, the

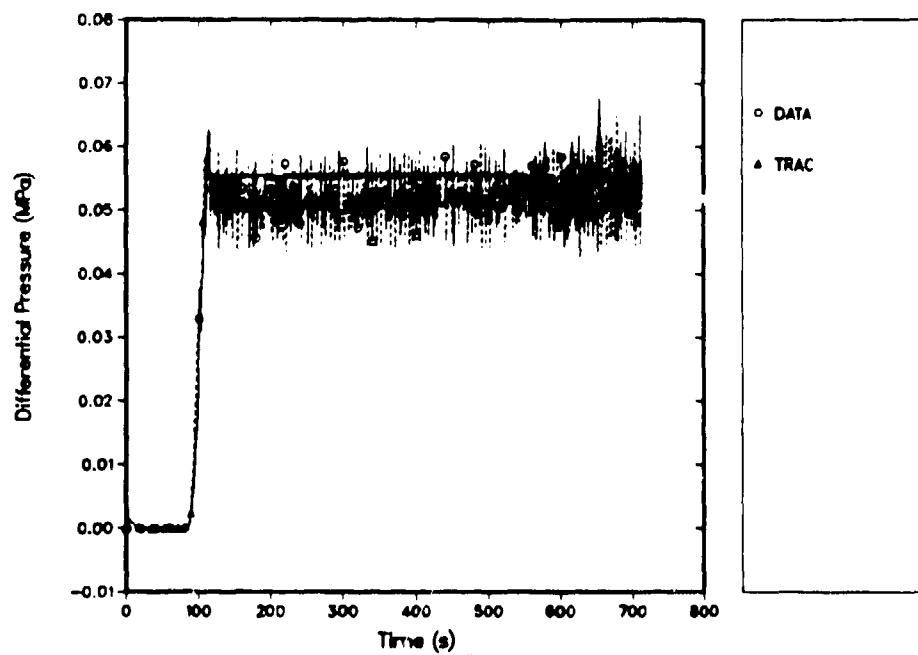


Fig. 13.
Downcomer liquid levels for CCTF Run 58.

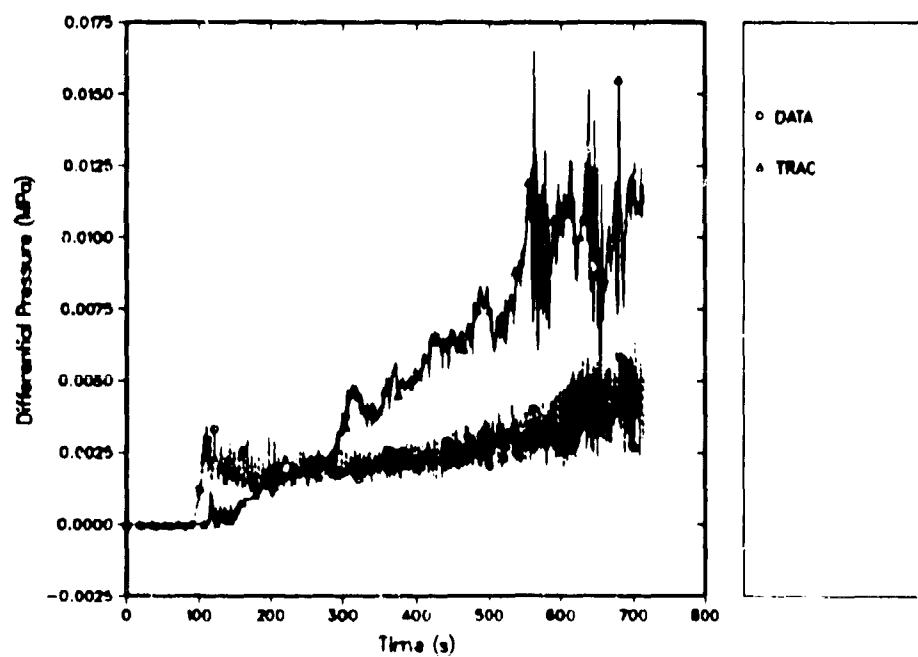


Fig. 14.
Core upper half liquid levels for CCTF Run 58.

downcomer ECC-injection rate was uncertain as a result of oscillations in the measurement. Because of uncertainties in our knowledge of facility configuration and operation, JAERI was requested to evaluate the facility configuration and operation. They did so by specifying the status of the RVVs and providing a recommended downcomer ECC-injection rate. This value was used in the calculation but some uncertainty in this key boundary condition remains.

After revising the input model per JAERI's recommended values for the RVV status and downcomer ECC-injection rate, Los Alamos determined that the CCTF input model was adequate in that no major deficiencies were identified. We note that the input model used a lumped representation of the intact loops with three loops modeled as one. We could identify no adverse impact on the calculated result because of this modeling decision. We did note that nonphysical pressure pulses were predicted as parts of the core quenched. This calculated phenomenon was also observed for SCTF Run 714. We have postulated that this may be related to the number of nodes used to model the core; coarse noding results in large quantities of cladding surface in a given calculational cell. The impact of noding on the calculated core behavior could be examined in a noding study.

With respect to the adequacy of the code constitutive models and correlations, we draw the following conclusions: (1) TRAC generally calculates the major trends of the test with the exception of an early core quench, (2) TRAC appears to underpredict the entrainment of downcomer liquid by vapor passing from the intact loops into the broken cold leg, (3) the core void distribution shows the effect of the interface-sharpener logic previously discussed (too much liquid below the quench front and too little above), and (4) nonphysical pressure pulses may be related to the code constitutive models and correlations. However, a noding study would be a necessary prerequisite to evaluating whether or not a code deficiency exists.

UPTF PROGRAM SUPPORT

We performed a posttest analysis of UPTF test no. 11. This test investigated the countercurrent stratified flow characteristics of a full-scale PWR hot leg. This situation is similar to the conditions that are hypothesized to occur in the event of a small-break LOCA in which the core is uncovered. Steam produced as a result of boiling heat transfer flows into the steam generator, is condensed on the tubes, and then flows back towards the vessel as condensate. This phenomena is known as "reflux condensation." It is of importance to determine whether TRAC can predict the countercurrent flow (CCF) of liquid in such a situation.

Tests runs were performed at 0.3 MPa and 1.5 MPa. The test procedure first established the water flow in the hot leg by injection into the inlet plenum of the steam-generator simulator (Fig. 15). Then a steady flow of steam was introduced into the core simulator, which because of the configuration of the facility was forced to flow countercurrent to the liquid flow in the hot leg of interest. This was done for a variety of steam flows to determine the CCF characteristic. The TRAC calculations were performed in the same manner.

The comparison of the TRAC results with the data are shown in Fig. 16. The results presented are in the form of dimensionless liquid flux delivered vs the dimensionless steam flow. These coordinates are typical of those used for the presentation of CCF data. The results show that TRAC underpredicts the countercurrent flow limitation (CCFL) point and, at the lower steam flows, overpredicts the amount of liquid delivery. However, for the test

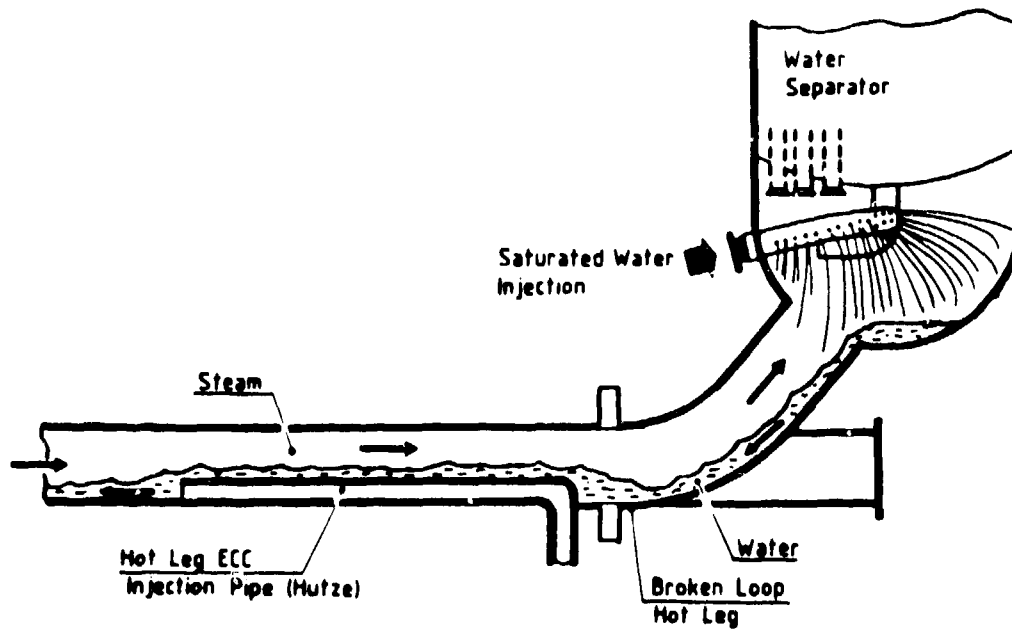


Fig. 15.
Test setup and procedure for the hot-leg CCF test in UPTF.

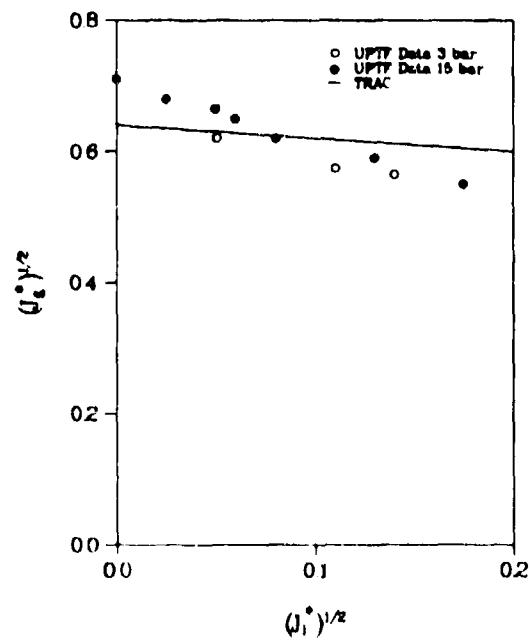


Fig. 16.
Comparison of the TRAC prediction with the full scale hot-leg CCF data from UPTF.

run that modeled the "reflux condensation" conditions typical of a PWR small-break LOCA, TRAC accurately predicted the complete downflow of liquid.

Analysis of the calculated results shows that TRAC predicts "on-off" CCF behavior, whereas the data suggest a smooth transition. In the course of TRAC development it was decided to use a constant value for the interfacial friction factor for stratified flow. This was necessary because available friction-factor correlations developed from small-scale data did not predict reasonable values when applied to full-scale geometry. Recent assessment of alternative correlations in TRAC has shown that a new model suggested by Ohnuki¹² better predicts the CCFL point, but still overpredicts the amount of liquid delivery at the lower steam flows.

Based on our assessment, we recommend that alternative correlations be further investigated in order to better predict the CCF phenomena in full-scale hot legs. The current version of TRAC underpredicts the CCFL point, but accurately predicts the complete delivery of liquid for conditions similar to those expected during a small-break LOCA reflux-condensation transient.

TRAC CODE IMPROVEMENT

From our assessment of TRAC against large-scale reflood data, we have typically enjoyed good success in predicting the overall core liquid inventory. However, in the detailed analysis, the predicted void-fraction distribution within the core shows too much accumulation below the quench front, and too little above the quench front. Also, during the transient reflood process, the code predicts sharp discontinuities in the void fraction occurring near the quench front, whereas the data show a smooth transition. These difficulties are caused by the core-reflood model, which restricts the amount of liquid leaving a hydrodynamic mesh cell (containing the quench front) based on a pool-entrainment correlation.¹³ This method of restricting the liquid flux is also referred to as the interface sharpener. To improve the prediction of the core reflood process, we investigated a drift-flux model for the void fraction¹⁴ as an alternative to the present core-reflood model. Moreover, the model eliminated the need for the interface sharpener. We assessed the model in an experimental version of TRAC-PF1/MOD2 against the CCTF Run 14 data because this test is prototypic of the bottom-reflood tests performed in the facility.

The results of the comparison are shown in Figs. 17–22. Here, we compare the predicted pressure drop at six intervals in the core to the data. Thus, the Δp contains the effect of the static pressure of the fluid, the interfacial and wall friction, and the temporal and spatial accelerations. In a reflood transient such as this, the static pressure of the fluid dominates; therefore, the plots represent primarily the liquid content. Also, since each interval is evenly spaced (0.61m), an estimate of the liquid fraction can be made from the pressure drops presented. The results show that except for the very bottom interval, the TRAC prediction is in reasonable agreement with the data. Work is continuing to investigate other methods for the core-reflood model. Also, we are investigating alternative correlations for the dispersed-flow film-boiling regime because the large amount of liquid that is known to exist above the quench front causes a very early quench with the current correlations.

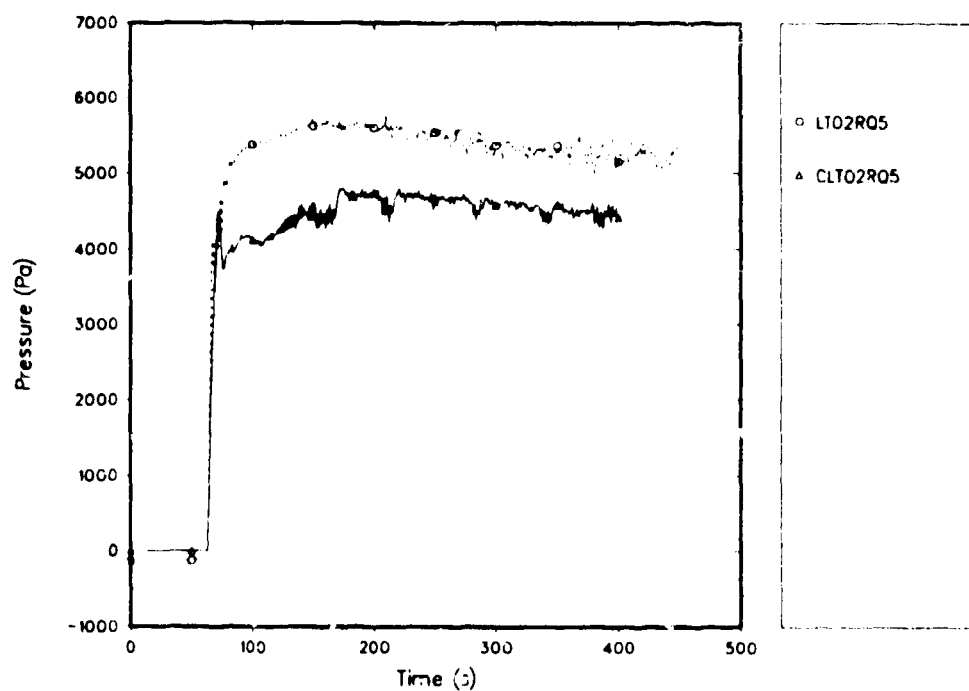


Fig. 17.

Comparison of the TRAC prediction with the CCTF Run 14 data for the core Δp at 0.0 to 0.61 m, where 0.0 m is the bottom of the core.

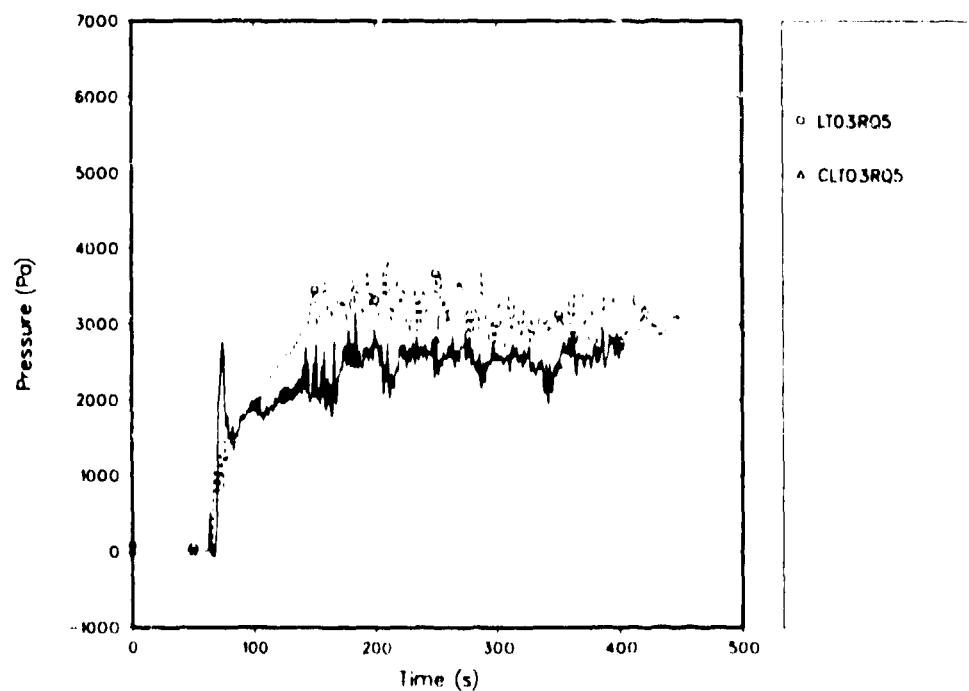


Fig. 18.

Comparison of the TRAC prediction with the CCTF Run 14 data for the core Δp at 0.61 to 1.22 m, where 0.0 m is the bottom of the core

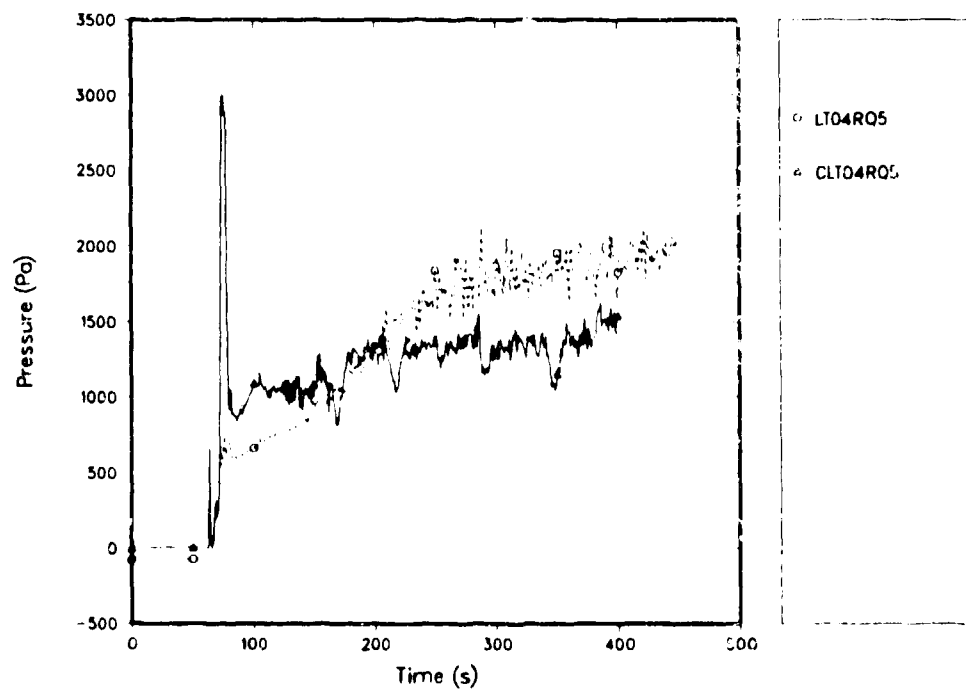


Fig. 19.

Comparison of the TRAC prediction with the CCTF Run 14 data for the core Δp at 1.22 to 1.83 m, where 0.0 m is the bottom of the core.

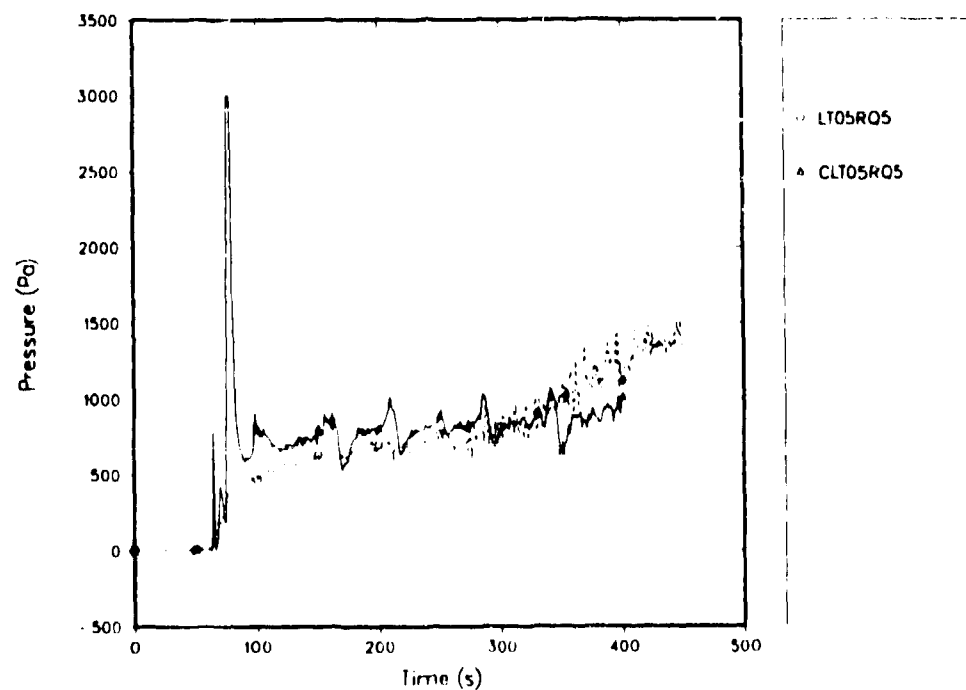


Fig. 20.

Comparison of the TRAC prediction with the CCTF Run 14 data for the core Δp at 1.83 to 2.44 m, where 0.0 m is the bottom of the core.

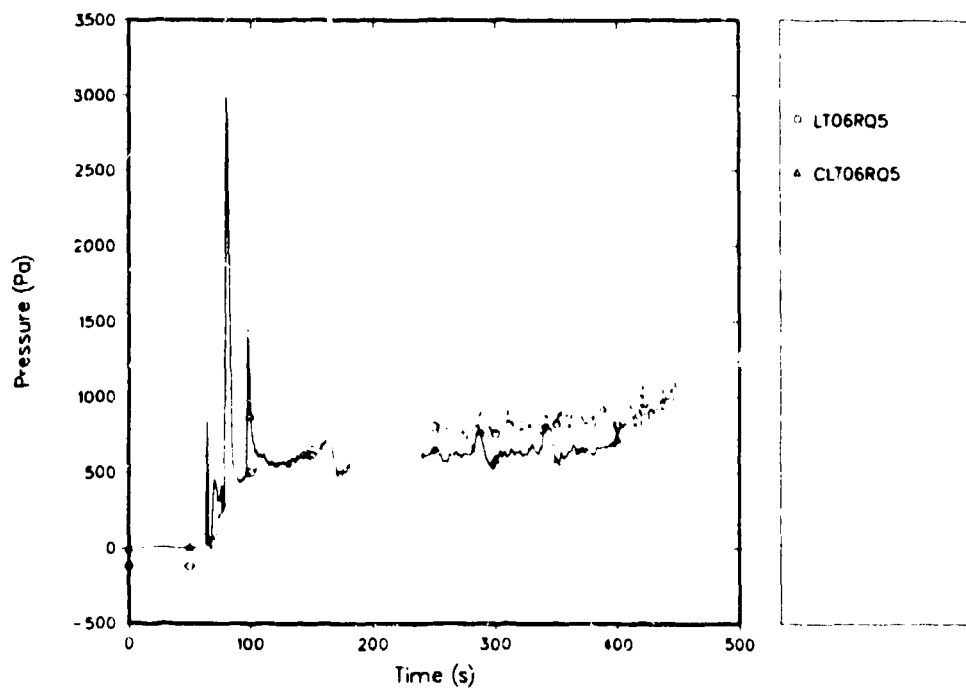


Fig. 21.

Comparison of the TRAC prediction with the CCTF Run 14 data for the core Δp at 2.44 to 3.05 m, where 0.0 m is the bottom of the core.

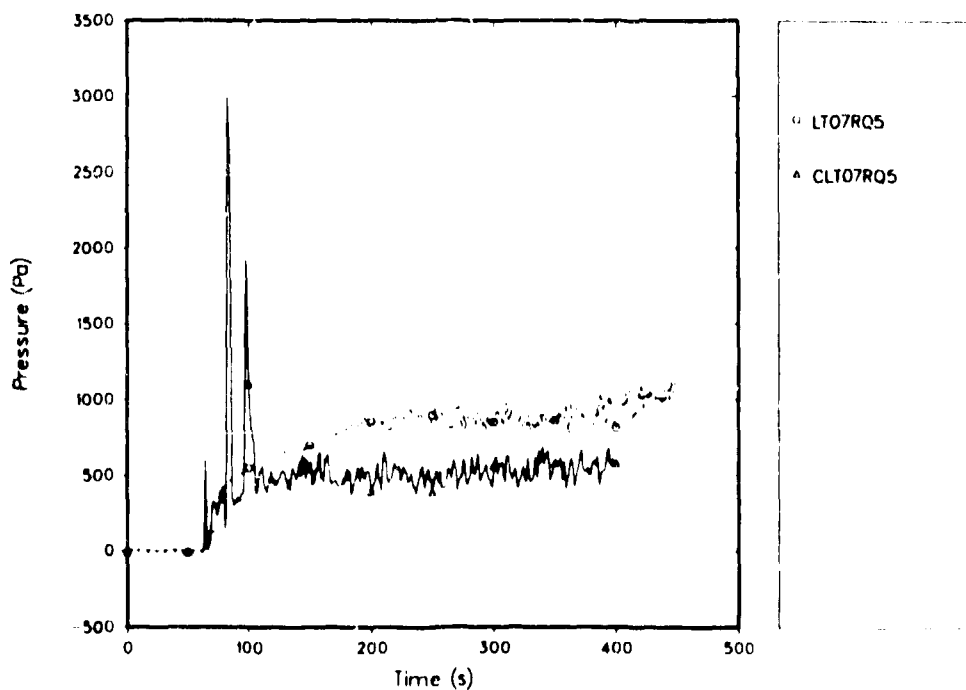


Fig. 22.

Comparison of the TRAC prediction with the CCTF Run 14 data for the core Δp at 3.05 to 3.66 m, where 0.0 m is the bottom of the core

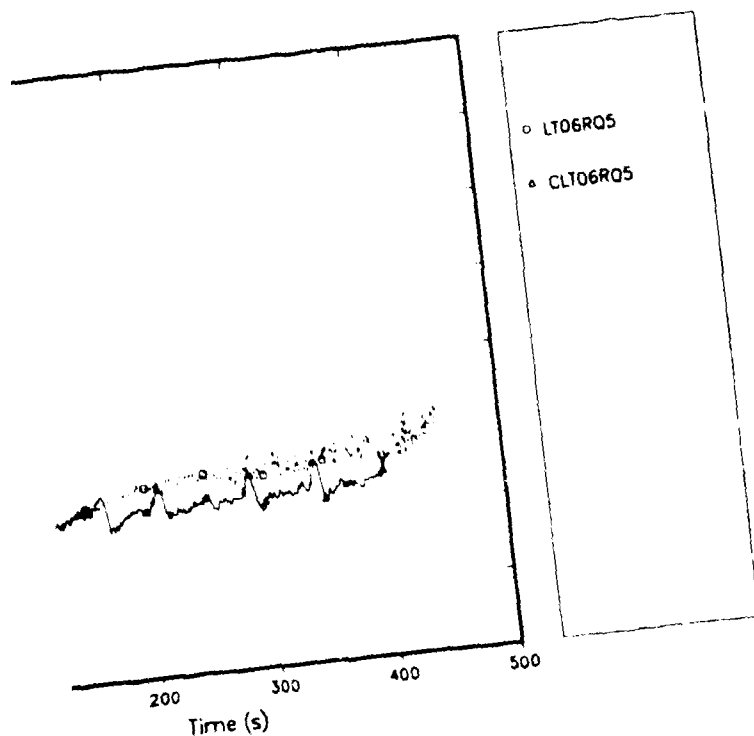


Fig. 21.
prediction with the CCTF Run 14 data for the core Δp at
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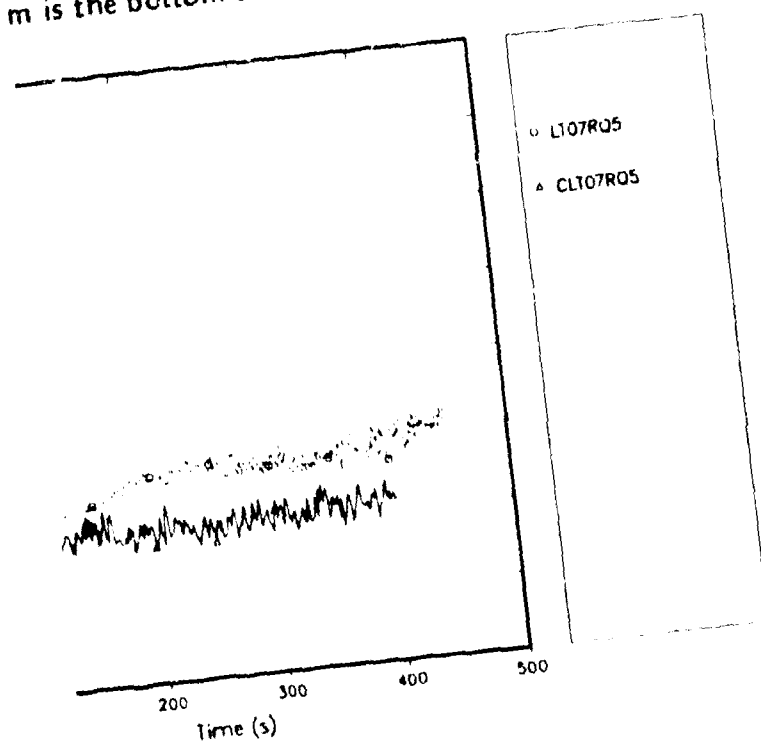


Fig. 22.
prediction with the CCTF Run 14 data for the core Δp at
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